Agriculture, Ecosystems and Environment, 30 (1990) 337-346
Elsevier Science Publishers B.V., Amsterdam — Printed in The Netherlands

An analytical assessment of Agroforestry Practices Resulting from Interplanting Cocoa and Kola on Soil Properties in South-Western Nigeria

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(Accepted for publication 25 January 1989)

ABSTRACT

Ekanade, O. and Egbe, N.E., 1990. An analytical assessment of agroforestry practices resulting from interplanting cocoa and kola on soil properties in south-western Nigeria. *Agric. Ecosystems Environ.*, 30: 337-346.

A mixed-crop plot of cocoa and kola at Cocoa Research Institute of Nigeria, Ibadan was resolved into four different randomized planting arrangements. Thereafter, soil samples were collected under them and analysed for bulk density, total porosity, particle size distribution, pH, organic matter, nitrate nitrogen, available phosphorus, calcium, magnesium, potassium, copper and zinc. The application of ANOVA and LSD statistics shows that the planting arrangement in which a kola stand is close and adjacent to two cocoa stands in a row (D) is the most beneficial to topsoil chemical properties when compared with other arrangements: row of kola between two rows of cocoa (A); single row of cocoa between two rows of kola (B); two rows of cocoa (C). The results imply that soil fertility status was best maintained under D. The major reason advanced for this situation is the synergistic relationship among the organic materials of both cocoa and kola, culminating in a high level of soil organic matter content and which did not occur under other planting arrangements which were more or less monocultural.

The present exercise appears to point to the fact that interplanting cocoa and kola to a specified pattern (a sort of tree-crop agroforestry) could be advantageous to soil fertility status, and might be easily adopted by peasant farmers since neither chemical fertilizers nor mulches would be required to maintain soil fertility.

INTRODUCTION

Many studies have indicated that soil properties degenerate in quality after the climax vegetation has been cleared in a humid tropical environment. This phenomenon does not appear to discriminate against a particular type of cultivation because it occurs under both food and tree cropping systems (Egbe, 1973; Aweto, 1981; Areola, 1984; Ekanade, 1985; Adejuwon and Ekanade, 1987).

Most of the works cited above have been carried out under monocultural

0167-8809/90/$03.50

plantations except the recent work of Ekanade (1987), which treats the spatio-temporal variations of soils under interplanted cocoa and kola. This implies that the consideration of soil properties under interplanted mature cocoa and kola using various spatial planting arrangements in a contiguous manner has not previously been examined. There is the need, therefore, to investigate what happens to soil as cocoa and kola grow together under different planting arrangements on a single plot. This is particularly necessary in view of the current trends towards the development of appropriate agroforestry systems in tropical agricultural practice.

In actual fact, it is a common practice among most of the cocoa farmers in the Nigerian cocoa belt to interplant their cocoa with other tree crops for two main reasons. First, the farmers aim at providing shade for cocoa and, secondly, they want to find a means of procuring more money and/or food from other tree crops to supplement that being realized from cocoa. Such tree crops, however, are usually planted haphazardly in this cocoa belt. The advantages and disadvantages of such interplantations, whether with food or tree crops, in terms of yield and management practice, are being investigated in many parts of the world under agroforestry systems (Ojeniyi and Agbede, 1980; Nair, 1984). So far the results of various findings appear to suggest that farmers do realize more income from interplanting than from monocropping of the three crops (e.g. Onwubuya et al., 1983). However, little or no attention has been given to the soil aspect under such interplantations (see Nair, 1984; Alvim and Nair, 1986). This study not only considers the status of soil under interplanted mature cocoa and kola subjected to varying planting arrangements in an experimental station, but also assesses the implication of such interplanting for land-use planning and management purposes in the cocoa growing areas of Nigeria.

STUDY AREA

The present study was carried out at the Gambari Experimental Station (G.E.S.) of the Cocoa Research Institute of Nigeria (C.R.I.N.), Ibadan. The specific plot was C.R.I.N.'s W8/1 covering about 2 ha planted with cocoa and kola. The Institute is located in the cocoa belt of south-western Nigeria (Fig. 1). The climate of the area is the tropical rain forest type characterized by a high mean annual temperature (about 27°C) with an annual temperature range that rarely exceeds 5°C and by a mean annual rainfall of about 1400 mm.

In general, the study area overlies metamorphic rocks of the Basement Complex, the majority of which are of the Precambrian age. Specifically, the plot under consideration is underlain by coarse-grained granites and gneisses. The derived soil from the latter has been classified under Iwo Association by Smyth and Montgomery (1962) and as the Plinthic Luvisols by F.A.O./U.N.E.S.C.O. (1974). The natural vegetation of the study area is the lowland evergreen trop-

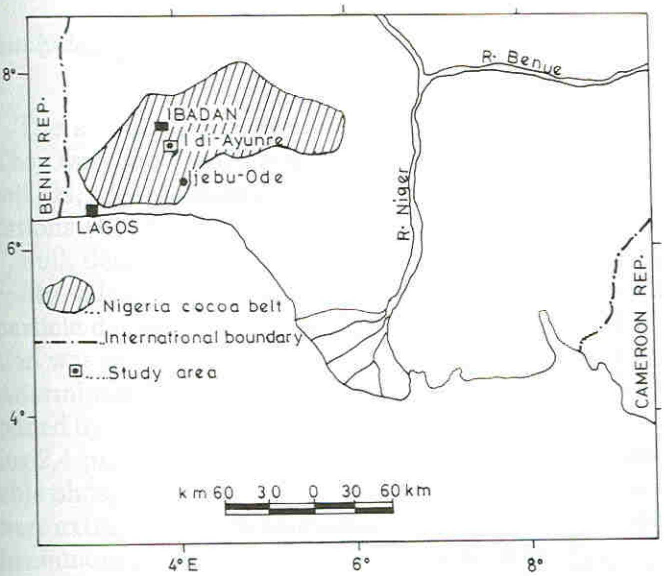

Fig. 1. The study area within the Nigerian cocoa belt.

ical rain forest, but it is now found only in patches. This indicates that the natural vegetation of the area has been greatly modified by the activities of man, especially by man's cultivation of the land resulting in a mosaic of secondary forests, fallow regrowths and tree crops, usually planted as monocultures but sometimes interplanted with one another at G.E.S. Such tree crops include cocoa, kola, coffee, oil palm, cashew, exotics (e.g. *Tectona grandis* and *Gmelina arborea*) and plantain/banana.

METHODOLOGY

Historical background

The plot (W8/1) used for this study, and covering about 2 ha, was cleared and planted to F3 Amazon cocoa (*Theobroma cacao*) in 1964 with the aim of interplanting it later with kola. In 1966, kola (*Cola nitida*) was planted. While kola was spaced 7.62 m apart, cocoa was spaced 3.05 m between kola interlines (see Fig. 2).

Experimental design

The cocoa/kola plot was resolved into four randomized planting arrangements that were considered capable of having different impacts on soil properties under them (Fig. 2). These arrangements include: (A) row of kola be-

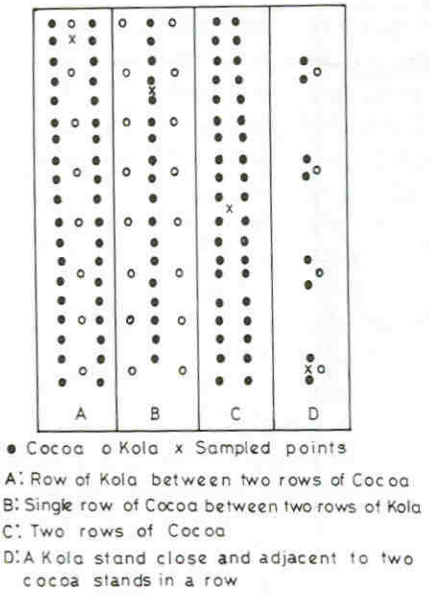

Fig. 2. Planting arrangements and sample points.

tween two rows of cocoa; (B) single row of cocoa between two rows of kola; (C) two rows of cocoa; (D) a kola stand close and adjacent to two cocoa stands in a row.

Soil sampling

Figure 2 shows how soil samples were collected under each planting arrangement. With regard to A and B planting arrangements the respective kola and cocoa trees were counted and numbered serially for each category. Thereafter, 10 of each were selected randomly using a table of random numbers. Soil samples were then collected under the selected kola tree (c. 1.5 m from the tree base) and between two cocoa trees. In the case of the C planting arrangement, the central points between four cocoa trees were also numbered serially and 10 were randomly selected for soil samples. Lastly, soil samples were collected from the D planting arrangement from spaces within the kola and the two cocoa stands, the point being equidistant from each stand. These were also numbered serially and 10 were randomly selected.

Soil samples were collected from 0–15 cm and 15–30 cm layers from each sample point as topsoil and subsoil, respectively. This sampling procedure indicates that 20 soil samples (10 from topsoil and 10 from subsoil) were collected from each of the four planting arrangements.

Analytical procedure

The soil samples were air dried, ground and passed through 2-mm sieve. They were analysed for bulk density, total porosity, particle size composition, soil pH, organic matter, nitrate nitrogen, available phosphorus, exchangeable cations (Ca^{2+}, Mg^{2+}, K^{+}) and micro nutrients (Cu, Zn).

Bulk density was determined by the core method (Blake, 1965). Total porosity values were computed from those of bulk density using the assumed particle density value of 2.65 g cm^{-3} (Vomocil, 1965). Particle size composition was determined by the hydrometer method (Bouyoucos, 1926) pH was determined in 1 N KCl in soil-solution ratio of 2:5 organic matter was determined by the Walkley–Black method. Nitrate nitrogen was determined by using 2,4-phenoldisulfonic acid on the prepared soil sample solution while available phosphorus was found by the Bray No. 1 method. Exchangeable cations were extracted in 1 N ammonium acetate leachate – potassium was determined in ammonium acetate leachate using the EEL flame photometer while calcium and magnesium were determined by direct titration with 0.01 N EDTA. Micronutrients were extracted with Na EDTA and the values of copper and zinc were determined with an atomic absorption spectrophotometer.

Statistical analysis

The major inferential statistical technique used in this study was the analysis of variance (ANOVA) which allows for simultaneous comparison of the planting arrangements. In addition to this, Fisher's least significant difference (LSD) test was used where the null hypothesis was rejected.

RESULTS

Soil characteristics under the planting arrangements

Table 1 shows the results of laboratory determinations of the soil properties under the four planting arrangements of interplanted cocoa and kola. The table shows that the topsoil structural properties are in a better condition under D than under all other arrangements. The recorded bulk density was 1.35 g cm^{-3} while total porosity was 69.0% under D. It could also be observed in Table 1 that all the topsoil chemical properties under D recorded the highest values except copper. In the subsoil the soil physical properties appear similar under the planting arrangements while there is no discernible distribution pattern with regard to subsoil chemical properties as observed in the topsoil.

TABLE 1

Mean values and ANOVA F ratios of soil properties under different planting arrangements

Soil property	Topsoil				ANOVA F ratio	Subsoil				ANOVA F ratio
	A	B	C	D		A	B	C	D	
Bulk density ($g\ cm^{-3}$)	1.39	1.38	1.40	1.35	1.52	1.48	1.43	1.42	1.42	2.17
Total porosity (%)	67.2	67.7	64.2	69.0	2.04	63.6	64.5	61.5	62.6	1.28
Sand (%)	70.9	71.7	73.2	70.8	1.82	70.0	70.0	68.8	69.2	0.60
Silt (%)	13.4	12.1	12.4	12.7	2.43	12.8	12.8	12.4	13.4	1.29
Clay (%)	15.7	16.2	14.4	16.5	1.21	17.2	17.2	18.8	17.4	1.48
pH (KCl)	6.4	5.2	4.9	6.6	3.96*	6.2	6.8	6.6	6.0	0.47
Organic matter (%)	3.8	3.1	3.4	4.0	3.06*	2.9	2.1	2.6	2.8	0.28
Nitrate nitrogen (ppm)	9.8	7.5	8.8	10.0	2.54	20.0	9.5	10.0	6.3	34.32*
Available phosphorus (ppm)	7.5	15.9	20.5	26.3	8.94*	26.0	22.5	30.0	20.0	5.43*
Calcium (mEq $(100\ g)^{-1}$)	4.4	5.1	5.3	6.6	4.31*	5.4	3.4	4.2	3.0	3.08*
Magnesium (mEq $(100\ g)^{-1}$)	1.1	1.0	0.9	1.8	3.75*	0.8	0.8	0.6	0.6	1.49
Potassium (mEq $(100\ g)^{-1}$)	0.7	0.4	0.5	0.9	2.97*	1.2	0.5	0.4	0.3	21.27
Copper (ppm)	1.8	0.9	-0.8	1.7	3.60*	0.8	1.1	1.2	1.5	2.97*
Zinc (ppm)	14.2	11.0	15.8	19.8	4.88*	11.6	6.5	10.8	12.4	2.24

A, row of kola between two rows of cocoa; B, single row of cocoa between two rows of kola; C, two rows of cocoa; D, a kola stand close and adjacent to two cocoa stands in a row.
ANOVA: $F_{0.05}$ (3:36)-2.87.
*Significant at 5% level.

Comparison of soils under the planting arrangements

The results of ANOVA comparing the soil properties under different planting arrangements are also given in Table 1. The bulk density, total porosity, % sand, % silt and % clay did not differ significantly in either the topsoil or subsoil under the four planting arrangements. However, the topsoil chemical properties did differ significantly among the planting arrangements, the only exception being nitrate nitrogen (see Table 1). In the subsoil, the soil chemical properties that differ significantly between the planting arrangements include nitrate nitrogen, available phosphorus, calcium, potassium and copper.

Isolation of the effects of the planting arrangements on soil properties

Table 2 shows the results of the LSD test ($P \leq 0.05$) involving only the soil properties in which the F test led to the rejection of the null hypothesis. From Table 2, the effect of each planting arrangement, whether it replenishes the soil more than other arrangements or not, can easily be recognized. Hence, it appears that the planting arrangement that replenishes most of the topsoil properties more than any other is the one in which the kola stand is close and adjacent to two cocoa stands in a row (i.e. D). It is also shown that the planting

TABLE 2

Results of the least significant difference applied to differences between treatment means

Soil property	Soil layer	AB	AC	AD	BC	BD	CD	LSD
Soil pH (KCl)	T	1.20*	1.50*	0.20	0.30	1.40*	1.70*	0.42
Organic matter	T	0.70*	0.40	0.20	0.30	0.90*	0.60	0.61
Nitrate nitrogen	S	10.50*	10.00*	13.70*	0.50	3.20*	3.70*	2.91
Available phosphorus	T	1.60	3.00	8.80	4.60	10.90*	5.80*	5.72
	S	3.50	4.00	6.00*	7.40*	2.50	10.00*	5.35
Calcium	T	0.70	0.90	2.20*	0.20	1.50*	1.30*	1.11
	S	2.00*	1.20	2.40*	0.80	0.40	1.20	1.22
Magnesium	T	0.10	0.20	0.70*	0.10	0.80*	0.90*	0.60
Potassium	T	0.30	0.20	0.20	0.10	0.50*	0.40*	0.34
	S	0.70*	0.80*	0.90*	0.10	0.20	0.10	0.25
Copper	T	0.90*	1.00*	0.10	0.10	0.80*	0.90*	0.38
	S	0.30*	0.40*	0.70*	0.10	0.40*	0.30*	0.27
Zinc	T	3.20	1.60	5.60*	4.80*	8.80*	4.00*	3.45

A,B,C,D, indicate planting arrangements.
*Significant at 5% level.
T, topsoil; S, subsoil.

arrangements in which single and double rows of cocoa are planted (i.e. D and C, respectively) appear to be least replenishing to the topsoil properties as indicated in Table 2. In the subsoil, the pattern is different, the planting arrangement consisting of rows of kola alone (i.e. A) replenishes most of the subsoil properties; surprisingly, D is not as beneficial as it is to the topsoil properties.

In specific terms, Table 2 shows that D is the most beneficial to most of the crucial topsoil properties. These include pH, organic matter, available phosphorus, calcium, magnesium, potassium and zinc. It is also relatively beneficial to topsoil copper. While A is mostly beneficial to topsoil organic matter and copper, C is relatively beneficial to available phosphorus and zinc in the topsoil. The planting arrangement in which single rows of cocoa (i.e. B) is used appears not to be as beneficial as other arrangements, to any of the topsoil properties at all. As mentioned earlier, the planting arrangement that appears most conducive to the subsoil properties is A. Such subsoil properties include nitrate nitrogen, calcium, potassium and, to some extent, available phosphorus. This planting arrangement appears to be of little benefit to subsoil copper content. The D planting arrangement does not seem to favour subsoil nitrate nitrogen, available phosphorus, calcium and potassium, but appears quite beneficial to subsoil copper. Arrangements B and C have the least favourable effect on most of the subsoil properties.

DISCUSSION

From the results obtained in this study it appears that different planting arrangements of a combination of cocoa and kola affect soil properties differently in spite of the similarities attributed to these tree crops in their early stages of development (Ekanade, 1987). It is, however, important to note that only the soil chemical properties are differentiated among these treatments because none of the soil physical properties differ significantly between the planting arrangements (Table 1). That the physical properties of soil under the various planting arrangements do not differ significantly seems to support the claim that textural properties are rarely affected by cultivation (e.g. Faniran and Areola, 1978). Probably more important in explaining the lack of significant difference in soil physical properties between the planting arrangements is the non-exposure of the ground surface under all of them. The non-exposure of the humid tropical land surface has been recognized to have far-reaching effects in protecting the soil textural and especially structural properties (Lal, 1975).

The soil chemical properties are differently affected by the various planting arrangements; in the topsoil, only nitrate nitrogen does not differ significantly. Since it has been suggested that the uniformity of their foliage cover is responsible for the non-significant differences in the soil physical properties among the treatments, there must be some other reason for these differences in the soil chemical properties.

Treatment D appears to maintain higher levels of most of the topsoil constituents than other treatments. This could probably be attributed mainly to the fact that organic-matter content appears to be maintained at a higher level under D than under any other treatment. For example, Aweto (1981) observed that the build-up of nutrients in the topsoil during the three fallow periods was due to the accumulation of soil organic matter which is the store and source of important nutrients, Areola (1984) also indicated highly significant correlations between organic-matter content and other soil chemical properties under cocoa. Furthermore, Areola et al. (1982) compared the role of organic-matter content in the build-up of soil fertility under forest and savanna fallows in south-western Nigeria and concluded that organic-matter content was more significantly correlated with other soil nutrients under forest than under savanna. This, they argued, was due to a greater amount of vegetation biomass producing a greater amount of litter in the former than in the latter plant community.

The higher level of organic matter content under D deserves some explanation, as the arrangements are contiguous although randomized. The phenomenon appears to be related to the nature of organic materials found under the planting arrangement. Ekanade (1987) has indicated that organic materials, especially leaves, emanating from kola appear to decompose faster than those emanating from cocoa because cocoa leaves are lignified. Hence, cocoa leaves decompose very slowly. Therefore, under a sole cropping of cocoa (as in B and C) the rate of nutrient returns to the soil through litter may be slower than under that of kola. In that case Treatment A should invariably bring about greater beneficial effects upon soil properties than D, since cocoa leaves would be expected to decompose slowly under D. What probably happens under D is a sort of synergistic relationship in which the rapid decomposition of kola leaves brings about a higher rate decomposition of cocoa leaves as well. In that case, more nutrients would be released to the topsoil under D than under those arrangements containing either kola or cocoa alone.

CONCLUSION

This study has shown that the differences in soil chemical properties under four different arrangements of interplanted cocoa and kola are significant. This implies that the various planting arrangements have different impacts on the soil chemical properties. Furthermore, the results show that of all the planting arrangements, that in which the kola stand is close and adjacent to two cocoa stands in a row appears to be the most beneficial to the soil. It is suggested that the probable cause of this phenomenon is the synergistic interactions among the litter components of cocoa and kola which give to higher levels of soil constituents than any of the monocultural arrangements. In any case, cocoa as a monoculture has been found to have deteriorating effects on soil properties over time (Kowal, 1959; Adejuwon and Ekanade, 1987). The latter workers recorded deteriorating indices ranging from 13.1% in the topsoil pH to 47.4% in topsoil magnesium under cocoa relative to the adjacent forest.

The findings of this study could have an important implication for soil management under tree crops, especially in the Nigerian cocoa belt. Hitherto, most Nigerian cocoa farmers have not adopted any definite pattern of interplanting cocoa with other tree crops. Hence, it has been difficult to assess soil productivity under such interplantation. The present study, however, appears to indicate that soil fertility could be enhanced by interplanting cocoa and kola in a particular pattern in such a way that a mixture of their litter materials culminates in the release of crucial nutrients to the topsoil. If this is so, there may be no need to apply either chemical fertilizers (cf. Kowal, 1959) or mulches (cf. Lal, 1975; Ekanade, 1985) for the proper management of soil under cocoa. The lifespan of cocoa trees may be longer (see Jolly, 1942; cf. Ekanade, 1985) in such a system and it may be possible to harvest kolanuts with little or no additional input to maintain soil fertility. All these definitely point to the fact that serious consideration has to be given to soil productivity in the development of appropriate tree crop agroforestry systems in which cocoa and kola, or other tree crops, are interplanted.

ACKNOWLEDGEMENTS

The authors would like to thank the technical staff of the Soils and Chemistry Division, CRIN and of the Department of Geography, Obafemi Awolowo University, Ile-Ife and Miss Roseline Aghogho Oghenekaro for their assistance in the analysis of the data; also the University Research Committee under Research Code No. 1423ER and the Director, CRIN for granting permission to collect data and publish this work.

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